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Challenges of management and therapy in patients with a functionally single ventricle after Fontan operation

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Abstract

Forty years ago, Fontan and Baudet performed the first life-saving operation on a patient with a functionally single ventricle. This multi-stage procedure established the connection between systemic venous circulation and pulmonary arteries. As a consequence, the pulmonary circulation is supplied in a passive way, whereas the single ventricle pumps the blood into the systemic circulation only.

Over the years, the technique of creating the abovementioned vascular connections has undergone several modifications. Due to the fundamental non-physiological hemodynamic relations between arterial pulmonary and systemic venous pressures, numerous complications can be observed in these patients including: supraventricular arrhythmias, thromboemboli, hepatic dysfunction, protein-losing enteropathy, heart failure, worsening cyanosis, systemic venous collateralization, and pulmonary arteriovenous malformations, as well as connective tissue lesions in bronchi.

Although based on an ingenious concept, the operation remains of a palliative character. Occasionally, heart transplantation is the ultimate resolution. Pharmacological therapy, and surgical conversion, often appear to be ineffective. However, this procedure has enabled many patients to reach adulthood and enjoy their lives to the full. This fact poses a great challenge for cardiologists wishing to become more knowledgeable and experienced as regards such patients, if we are not to waste such fabulous surgical achievements. (Cardiol J 2011; 18, 2: 119–127)

Key words: Fontan operation, long-term follow-up, complications, management

Introduction

A palliative procedure that has been performed since 1971, named after Fontan and Baudet, is the method of treatment for patients with a functionally single ventricle [1]. A diagnosis of univentricular heart includes the broad category of congenital cardiac malformations, characterized by both atria related entirely, or almost entirely, to one functionally single ventricular chamber. The discussed procedure was first designed and introduced as a management for tricuspid atresia, which, actually, is the commonest form of univentricular heart. The rationale for this operation is to reduce the volume and pressure overload of the single ventricle and to normalize blood oxygenation. This is achieved by creating a complete separation of the pulmonary circulation from the systemic circulation [2, 3].

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Fontan operation

The procedure is accomplished in stages, with the first step aimed at supplying an adequate pulmonary perfusion. A decreased pulmonary blood flow caused by a significant pulmonary stenosis requires an arterial systemic-to-pulmonary connection to be performed (modified Blalock-Taussig shunt). In patients with unrestrictive pulmonary blood flow, an initial palliation may consist of pulmonary artery banding, which unfortunately has been associated with adverse outcomes late after the Fontan procedure [4].

At around the sixth month of life, a procedure termed a Glenn shunt is performed, in which a bidirectional cavopulmonary anastomosis (superior vena cava — pulmonary artery) is created in order to reduce volume overload of the single ventricle. Concurrently, the pulmonary perfusion evolves from the fetal high-resistant into the low-resistant circulation. The Fontan procedure is completed later, some time between 18 months and four years of age, thereby separating pulmonary from systemic circulation. The classic Fontan procedure involves a valved conduit between the right atrium and pulmonary artery. However, the specificity of circulation created in this way and its physiology require proper selection of patients strictly fulfilling the criteria originally called the 'Choussat commandments'. The most important of these, beside the patient's age, are: low pulmonary vascular resistance (below 4 Wood units/m^2 body surface area), sinus rhythm, preserved systolic function of the single ventricle, absence of a significant atrioventricular regurgitation, normal systemic venous return, and normal right atrium volume as well as absence of pulmonary artery distortion [5]. The principle of the operation is to create a direct connection between systemic venous circulation (venae cavae superior and inferior) and pulmonary arteries without an interposed subpulmonary ventricle. As a consequence, the blood flows into the lungs in a passive way. Thus, adequate pulmonary perfusion is achieved, as well as a decrease in volume overload of the single ventricle, now responsible only for supplying the systemic circulation.

Modifications of Fontan operation

Since 1971, many modifications of the Fontan procedure have been introduced to encompass several forms of palliative surgery that divert systemic venous return to the pulmonary artery [1]. Most adults encountered today will have had a modified

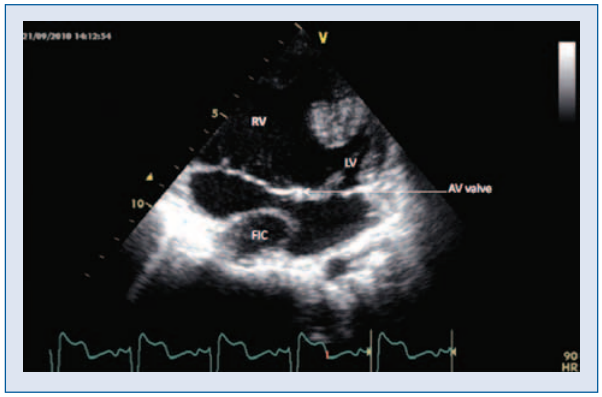

Figure 1. Unbalanced common atrioventricular canal after the Fontan operation — a four-chamber view; RV — right ventricle; LV — rudimentary left ventricle; FIC — fenestrated intraatrial conduit; AV valve — common atrioventricular valve.

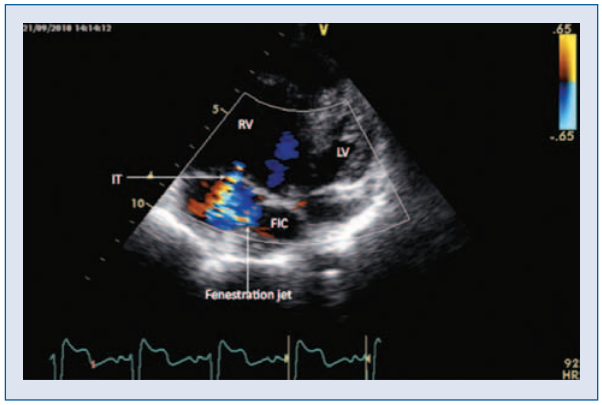

Figure 2. Unbalanced common atrioventricular canal after the Fontan operation — a four-chamber view with color Doppler imaging; RV — right ventricle; LV — rudimentary left ventricle; FIC — fenestrated intraatrial conduit; IT — tricuspid insufficiency.

Fontan procedure based on creation of direct anastomosis of the right atrium to pulmonary artery.

In 1987, de Leval proposed a major variation that consisted of an end-to-side anastomosis of the superior vena cava to the right pulmonary artery, a composite intraatrial tunnel with the right atrial wall and a prosthetic patch to channel the inferior vena cava to the transected superior vena cava [6]. Total cavopulmonary connection (TCPC) may also be accomplished by means of an extracardiac tunnel, where blood from the inferior vena cava flows directly to the pulmonary artery via an external conduit [7]. Fontan pathways are currently fenestrated by creation of an interatrial communication, which may be beneficial early after surgical procedure (Figs. 1, 2) [8]. At a later stage, fenestration

can be closed by transcatheter approach. The modifications presented above resulted from a search for the optimal solution that would enable functioning of the hemodynamic system created by Fontan, where the systemic venous pressure provides the only impetus for blood inflow to the lungs and, as a consequence, safeguards cardiac output. Such a situation is possible only if the pulmonary arterial pressure is decreased at the expense of a small increase in the systemic venous pressure.

Longstanding observations

Long-term follow-up proves beyond any doubt that the Fontan operation is based on the correct concept. Before the implementation of this treatment, 90% of children with a functionally single ventricle died before their first birthday [9]. In the most comprehensive follow-up, comprising only 83 non-operated patients with a single morphologically left ventricle, it was observed that 70% of them died before their sixteenth birthday [10]. A right ventricular morphology entailed an even worse prognosis, as only 50% of children survived more than four years after diagnosis [11]. In this context, patients after a Fontan operation have a considerably better prognosis, with 12-year survival having been observed in 83% of patients operated on using the method of atriopulmonary connection [12] and ten-year survival has been reported in 91% of patients in whom the lateral tunnels technique was applied [13].

Khairy et al. [14] even described a 20-year survival rate of 82.6% of patients, and unexpectedly found no differences among patients operated on by various methods. The presented analysis demonstrated that the risk factors for death in this population included protein-losing enteropathy (a complication discussed further in this paper), single morphologically right ventricle and increased right atrial pressure.

Complications after Fontan procedure

The modifications of Fontan operation still remain an intellectual challenge for cardiac surgeons. There are some unavoidable complications, resulting from the fundamental non-physiological hemodynamic relations between arterial pulmonary and systemic venous pressures, which eventually constitute the physiology of the so-called 'failing Fontan'. Consequently, potential complications are numerous and include arrhythmias, thromboemboli, hepatic dysfunction, protein-losing enteropathy, heart failure (HF), worsening cyanosis, systemic venous collateralization, pulmonary arteriovenous malformations and connective tissue lesions in bronchi.

Rhythm and conduction disturbances

Supraventricular arrhythmia is a common cause of hospitalization among patients with a univentricular heart after Fontan. Its frequency increases steadily with the patient's age and the post-operative interval, with at least 50% of patients experiencing atrial tachycardia by 20 year follow-up [15]. The commonest mechanism for symptomatic tachycardia is macroreentry within atrial muscle [16], the so-called 'intra-atrial reentrant tachycardia' or 'incisional tachycardia'. That kind of arrhythmia is usually slower than a typical atrial flutter which may be encountered in a structurally normal heart, and is a consequence of the cardiosurgical intervention as well as of intrinsic histopathological features of the atrium. Histopathological examination of the atrial muscle in patients with tricuspid atresia has shown an abnormal atrial fiber array that may predispose to the slowing of conduction necessary for reentrant rhythms [17].

Other elements contributing to arrhythmia are: anatomic structures such as orifices of inferior and superior venae cavae, atrial septal defect or the os of the coronary sinus, further compounded either by the atrial suture lines or the atriopulmonary anastomosis [16]. Moreover, residual hemodynamic abnormalities cause a distention of atrial wall tissue, which subsequently leads to sinus node dysfunction. This chain of pathological conditions predisposes to an irregular atrial rhythm, which is a trigger of supraventricular tachycardia. According to the analysis performed, factors conducive to the discussed arrhythmia in patients after Fontan procedure are: older age at the time of surgery, sinus node dysfunction, early post-operative arrhythmias and anatomy of double inlet left ventricle [18]. Supraventricular arrhythmia complicating the clinical course gives an incentive to seek new operative techniques. The lateral tunnel method, promising during the initial follow-up period, has been proven ineffective in protecting against progression of arrhythmias in the long run [19]. A modification including creation of an extracardiac tunnel, thus minimizing the number of atrial sutures, results in a lower incidence of arrhythmia, although post-operative follow-up of patients is still scarce [20]. An extracardiac tunnel, however, precludes an ablation procedure. Patients with a significant atrioventri-

cular regurgitation may develop a 'left-atrial' arrhythmia which is an atrial fibrillation. The presence of supraventricular arrhythmia is a common cause of aggravation of HF and emergence of thromboembolic complications, and therefore requires vigorous treatment.

The recently published survival analysis in a Fontan population revealed a steadily increasing risk of sudden death which could be a consequence of either intraatrial reentrant tachycardia with rate 1:1 conduction, or ventricular arrhythmia, which is a frequent complication of HF itself [14]. Therefore, acute onset of tachycardia is an indication for urgent cardioversion. A typical prior anticoagulative management is not required [21], as the risk of sudden death in this particular group of patients is enormous. Transesophageal echocardiography also does not increase the likelihood of avoiding embolic complications [16]. Treatment of the discussed arrhythmia still remains empirical, based on the experts' opinion. There are no available studies conducted according to Evidence Based Medicine (EBM) rules. Typically, beta blockers and digoxin are used as they lack negative inotropic effects [22]. Amiodarone is not recommended by some authors because of its thyroid and pulmonary side effects. Others, in turn, advocate its broad application, because it does not impair the single ventricle systolic function [23].

One must bear in mind, however, that most antiarrhythmic drugs reduce heart rate, which may subsequently lead to a drop of cardiac output, poorly tolerated by patients with a single ventricle. The occurrence of supraventricular arrhythmia may be the first indicator for hemodynamic complications of Fontan circulation. These are caused by a rise in blood pressure at any level (stenosis of pulmonary veins, arteries or artificially created anastomoses, presence of newly emerged arteriovenous collaterals) and should be investigated either with noninvasive or angiographic examination and dealt with as soon as possible [24, 25]. Unfortunately, effective elimination of cardiac arrhythmia after hemodynamic improvement is achieved only in one third of Fontan patients [16]. A surgical conversion from the atriopulmonary connection to the intra- or extracardiac TCPC with concomitant cryoablation or Maze procedure of atrial walls seems well-justified in such clinical situations [26, 27]. In extreme cases, difficult to control arrhythmias may require heart transplantation [25, 26, 28].

An encouraging method of treatment for supraventricular arrhythmia is radiofrequency ablation. This remains, however, a great challenge for electrophysiologists. Limitations of the procedure in Fontan patients include: diversity of circulating stimuli, difficult approach to the atrium, anatomical complexity and uniqueness. The effectiveness of this procedure reaches 80% [26, 29]. Unfortunately however, the recurrence of tachycardia during short follow-up has been reported as 30––66% [26, 30]. As mentioned above, bradycardia, either iatrogenic or caused by sinus node dysfunction, might be a triggering factor for supraventricular arrhythmia.

Therefore, according to some authors [31], it is justifiable to implant epicardial electrodes during the initial operation. The need for permanent heart pacing derives also from the fact that loss of sinus rhythm caused by sinus node dysfunction occurs frequently, and increases in frequency with a longer duration of follow-up. Due to lack of access to the right ventricle, epicardial stimulation is utilized in most cases, while dual-chamber stimulation is implanted in extremely experienced centers only (with one electrode placed epicardially, the other in the sinus venosus) [25, 26, 32].

Thromboembolic complications

Thrombotic events occur in 3% to 33% of Fontan patients, apparently the highest prevalence among all groups of adults with congenital heart disease. Moreover, thromboembolism is probably the leading cause of death among these patients [33–38]. Its pathogenesis in Fontan patients is still a matter of debate. This condition contributes to the failure of Fontan circulation and may occur with increased frequency in 'failing' Fontan circulation [2, 33, 34]. There has been a report of a sharp increase in risk for thromboembolic death 15 years after Fontan surgery [14]. The underlying hemodynamic mainstay of these complications includes distended and sluggish Fontan pathways and atrial arrhythmia conducive to hemostasis and hypercoagulable states. The latter include decreased levels of protein C, protein S, antithrombin III, factors II and X, as well as increased platelet reactivity [37]. Concurrently, a moderate factor VII deficiency has been described in these patients, something which should predispose to bleeding, rather than to coagulation, therefore making the pathogenesis of thromboembolic complications even more complex [33]. Clotting factor abnormalities are to a large extent the result of hepatic impairment caused by hemodynamic complications. Specifically, in patients after Fontan operation, hepatic congestion and cirrhosis are common, unlike hepatic adenoma and carcinoma

which seldom appear [2]. In the so-called Fontan circuit, surgically created pathways between the venae cavae and the pulmonary arteries are the commonest places for thrombus formation which may further embolize or extend into the pulmonary arteries [33]. Thrombi may also originate in the pulmonary venous pathway, systemic ventricle or ligated pulmonary artery. The presence of intracardiac communication (fenestration) poses a threat of paradoxical embolism. In such clinical situations, morbidity occurs principally in the form of embolism in the central nervous system [34]. Risk factors of thromboembolic complications in the analyzed population are still unspecified, probably due to the anatomical diversity of the study group and the constantly changing methods of surgical treatment. A correlation between thromboembolism and factors including age at operation, type of procedure performed, low cardiac output, arrhythmia, polycythemia [37] or fenestration [33, 36, 37] remains unproved despite the pathophysiological justification and probability of event coincidence. Pulmonary artery stump is the only factor of proven undesirable significance [36]. All these facts may contribute to a lack of efficient treatment of the mentioned complications. Administration of heparin, coumarin derivatives, aspirin, or a combination of all of these, or not taking any of them, does not influence therapy outcomes [33–35]. Lately, however, there have appeared even more reports recommending coumarin derivatives, especially in the presence of a dense spontaneous echocontrast in the right atrium as well as in the cohort of patients operated on using more recent techniques [38]. It has been proven that one of the risk factors for death in this population is no anticoagulant therapy taken, which is an argument justifying application of such treatment [14].

Protein-losing enteropathy

A condition particularly hazardous for developing thromboembolic events is protein-losing enteropathy (PLE), a typical post-Fontan complication. It occurs at an incidence of 1.5% to 11%, with onset reported to range from as early as one month to 20 years (mean of approximately seven years) after Fontan operation [39–41].

The probable cause of PLE derives from the essence of Fontan circulation based on the chronically elevated right atrial pressure with the subsequently increased inferior vena caval and portal vein pressures. This elevation in abdominal venous pressure presumably leads to intestinal congestion, lymphatic obstruction and enteric protein loss [39]. Additionally, a univentricular heart often develops poor compliance and diastolic dysfunction, which subsequently contribute to low cardiac output. This situation in the face of elevated venous pressure predisposes the patients to mesenteric ischemia, which results in intestinal mucosal injury culminating in the onset of enteric protein losses. At the same time, it has been observed that not all patients with PLE have exhibited increased systemic venous pressure, which suggests a more complex mechanism of the discussed phenomenon [25, 39, 41].

It is assumed therefore that the additional cause of intestinal epithelial membrane injury is a hitherto unknown infectious agent [42]. Protein-losing enteropathy is more frequent among patients with a single morphologically right ventricle and those with longer cardiopulmonary bypass time. This last finding suggests a potential role of the perioperative cardiac injury in the pathogenesis of this complication. On the other hand, it may serve as an indicator for more difficult operation due to anatomic complexity that distinguishes higher risk patients [40]. Laboratory findings show PLE patients exhibit low levels of serum proteins, albumins in particular, and increased faecal alfa1 antitrypsin levels [24, 25]. The degree of clinical manifestation varies widely, from clinically asymptomatic to chronically debilitating. The commonest clinical presentation is fluid retention that occurs as the result of reduced vascular oncotic pressure due to enteric protein loss and manifests itself by means of peripheral edema, fatigue, pericardial and pleural effusions as well as ascites. These conditions are often concomitant with chronic diarrhea [2, 41]. As a consequence of chronic loss of immunoglobulins and intestinal lymphangiectasia resulting in lymphocyte depletion, patients are susceptible to infections. Occasionally, PLE is demonstrated by a thromboembolism as a consequence of anticoagulant proteins loss [39, 43]. The prognosis for patients with PLE is very poor, with mortality rates of 30% at two years and 50% during the following five [39, 40, 43]. Treatment of proven effectiveness does not exist and any therapeutic successes remain anecdotal. Hence, it is essential to exclude all potential hemodynamic and arrhythmic complications that would require medical intervention. Unfortunately, PLE may manifest itself even with optimal Fontan palliation. The medical therapy of this complication is three-directional and involves membrane stabilization, improvement in ventricular function and protein homeostasis through nutritional support and protein replacement treatment.

Due to the pathomechanism of PLE, an intravenous albumin supplementation does not provide any stable effect. Therefore, securing a high-protein diet and, due to fat malabsorption from intestinal lymphatic dilatation, a high medium-chain triglycerides diet, is essential [43, 44]. Hemodynamic improvement is achieved mainly by the combined use of diuretic therapy and attempts to augment cardiac output by reduction of afterload or by means of inotropic support. Treatments comprise angiotensin-converting enzyme (ACE) inhibitors, phosphodiesterase inhibitors or beta-blockers. In some patients with PLE, aldosterone-receptor antagonist therapy reduces proteinuria. But whether the effect is secondary to changes in intraventricular volume and pressure, or is achieved through direct mineralocorticoid receptor antagonism remains unclear [45]. It has been reported that PLE may sometimes be a complication of autoimmune and inflammatory processes such as those seen in the course of lupus erythematosus and sarcoidosis, suggesting an inflammatory response as an underlying cause of protein intestinal losing. This finding was the basis for the administration of corticosteroids (25–60 mg of prednisolone per day) with quite a good effect, although confirmed only by anecdotal reports. In addition to an increase in albumin levels, this therapy improves levels of immunoglobulin G [39]. Unfortunately, discontinuing steroidotherapy results in recurrence of symptoms [46]. Chronically elevated pressure in the venous vascular bed is thought to interfere with the production and distribution of sulfated glycosaminoglycans such as heparin sulfate which are involved in the regulation of albumin losses. Therefore, attempts have been made at heparin therapy with, according to some authors, a significant clinical improvement resulting from the inhibition of protein escape [47].

In patients with PLE, hypocalcemia may be a clinical consequence of hypoproteinemia and vitamin D deficiency caused by fat malabsorption. Calcium supplementation enhanced by administration of vitamin D causes normalization of this element in serum levels. Moreover, in some patients with PLE this treatment, through an unknown mechanism, reduces proteinuria and visibly improves patients' clinical state [48]. Lymphocyte and immunoglobulin loss predispose to considerable immune deficiency. Unfortunately, immunoglobulin supplementation yields only a short-term improvement, meaning that vaccinations are recommended [49]. Thus, periodic administration of fresh frozen plasma in order to replenish stores of proteins C and S, as well as antithrombin III to avoid a prothrombotic state, would be justified [33].

Heart failure

Subsequent to Fontan palliation, the separation of systemic circulation from pulmonary circulation is designed to reduce the volume overload of the single ventricle. Nevertheless, the single ventricle has to sustain systolic function securing both circulations, which inevitably leads to its insufficiency.

A Fontan operation is performed in several stages in order to enable reduction in ventricular size and wall thickness, which in turn increases ventricular contractility. However, systolic and diastolic functions of the single ventricle remain impaired as a result of the preoperative chronic volume overload as well as the typically co-existing, abovementioned, aortopulmonary collaterals [50]. Impaired exercise capacity in analyzed patients is also associated with reduced vital capacity, high residual volume-to-total lung capacity ratio and skeletal muscle dysfunction [51]. Such a condition manifests itself by the typical HF symptoms: exercise intolerance, dyspnea and fatigue. Objective quantification via a cardiopulmonary exercise test confirms a significantly reduced aerobic capacity [52]. It has been proven that higher oxygen uptake is characteristic of patients with a single morphologically left ventricle [53]. Heart failure is an acknowledged risk factor for death in patients after Fontan operation, especially concerning patients with a single morphologically right ventricle [14, 41]. Treatment of this condition is based on the rules applying to the general population of patients, completed with experts' opinions, retrospective data collection and small, single-center studies. Similarly to the case of antiarrhythmic treatment, there are no available studies into HF therapy in this group of patients supported by EBM. Angiotensin-converting enzyme inhibition is frequently used in patients with failing Fontan circulation. Elevated levels of hormones that modulate fluid homeostasis including aldosterone, renin, angiotensin and antidiuretic hormone have been demonstrated in most Fontan patients [25]. Exceptionally high levels of the abovementioned hormones characterize HF [54]. Application of ACE inhibitors reduces vasoconstriction, subsequently decreasing end-diastolic pressure and improving cardiac output. Another group of drugs used in chronic HF are beta-blockers. They diminish the increased adrenergic activation typically encountered in HF that leads to myocardial hypertrophy and apoptosis.

One must bear in mind, however, that negative chrono- and dromotropic effects of beta-blockers are particularly harmful for this population. On the other hand, it has been observed that these drugs, combined with ACE inhibitors or in monotherapy, usually lessen symptoms and lower mortality [55, 56]. Fluid retention as the effect of HF requires administration of loop diuretics. Use of spironolactone is also well-advised. When applying dehydrating therapy, sometimes necessarily aggressive, one must remember to sustain an appropriate preload, which in this specific group of patients is crucial by means of preserving the cardiac output. Some authors advocate the use of nesiritide, a recombinant B-natriuretic peptide, as a new and promising medication in the therapy of acute HF. It acts through regulation of vascular tone and fluid homeostasis, causes arterial and venous dilatation without reflex tachycardia, and possesses lusiotropic properties, all of which improve cardiac output. Although this particular group of patients would enormously benefit from such therapeutic effects, clinical experience of applying nesiritide in congenital heart disease is unfortunately negligible [24]. In acute HF, some authors recommend inotropes — phospohodiesterase inhibitors [25].

Lastly, advanced HF, usually accompanied by the above clinical complications which constitute the physiology of 'failing Fontan', is an indication for the revision of the atriopulmonary connection to the lateral or extracardiac cavopulmonary connection. It is performed under the assumption that coronary perfusion will be improved by placing the coronary sinus in the lower pressure atrium, and that the fluid dynamics of the cavopulmonary type connection reduces energy loss [57]. Heart transplantation is considered to be the ultimate resolution, yet practically it is not widely available due to technical problems of a re-sternotomy and markedly altered heart anatomy, as well as limited donor supply [57, 58].

Cyanosis

The vast majority of Fontan patients present with normal, or near normal, oxygen saturation [2, 25, 41]. A small degree of desaturation (usually exceeding 94%) originates from the anatomical conditions deliberately created in a Fontan operation, where venous blood from the sinus venosus flows into the atrium and mixes there with oxygenated blood from pulmonary veins. Occasionally, a giant right atrium compresses the pulmonary vein [2, 59]. An increase in the right atrial pressure may also be responsible for the development of vascular Fontan-systemic connections. Venovenous collaterals, in turn, are frequently observed in patients after bidirectional cavopulmonary anastomosis [59]. In advanced cases, cathether embolization of these blood vessels should be considered. Cyanosis may also result from a right-to-left shunt through an atrial fenestration or a leak of the inferior vena cava to right pulmonary artery baffle. Both types of this intracardiac communication, after an earlier hemodynamic evaluation, may be safely closed by devices, thereby reducing subsequent need for anticongestive medication and improving oxygenation [60]. Desaturation is also an effect of progressive drop in single ventricle competence [50]. Moreover, a hallmark of Fontan pulmonary circulation is the non-pulsatile flow that results in a reduced release of endogenous nitric oxide, an endothelial vasodilatator, along with an increased activity of endothelin. In some patients, it may cause a progressive rise in pulmonary pressure. A rare, but mostly lethal, pulmonary complication is the so-called plastic bronchitis, in which protein deposits are present in bronchi. Urokinase therapy remains a dramatic attempt at treatment in such cases.

Pregnancy

Hemodynamic changes observed during pregnancy (increased cardiac output, heart rate and stroke volume, with simultaneous drop in vascular resistance) create extremely disadvantageous conditions for women after the Fontan operation. In fact, dependence on the venous return in these patients poses some limitation on the ability to secure an adequate cardiac output. For this reason, there have been few case studies published of pregnancies after Fontan operation [61–64]. Fortunately, there are no reports of maternal deaths; however, an exacerbation of arrhythmia and a transient deterioration of HF are frequent. Moreover, there is a serious threat of thromboembolism and paradoxical emboli, if the Fontan is fenestrated [25]. The ratios of miscarriages and number of lower birth weight newborns are higher than in the healthy population. Despite the anticipated complications, pregnancy in women after Fontan palliation is not contraindicated. It must be, however, carefully planned and managed in specialist centers [63, 64]. When deciding on motherhood, women with a single ventricle after cardiac surgery must be made aware of their life expectancy to make informed choices as to their ability to raise the child.

Conclusions

The Fontan operation and its variable modifications are the most remarkable and important developments in cardiac surgery in recent decades. This ingenious approach, although of a palliative nature only, has allowed for the survival of patients with heart anomalies previously considered lethal. Today, this newly emerged patient population represents a challenge for 'adult' cardiologists, if we are not to waste such fabulous surgical results.

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